An Australian Insensitive Booster Composition

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Abstract

The development of a new pressed booster composition designed for use in Australian ordnance that will meet Insensitive Munition (IM) criteria is described. The impact sensitiveness, shock sensitivity and cookoff response of a wide range of PBX compositions containing blends of nitramines (RDX or HMX) with other explosives (PETN, TATB) and a range of binders have been assessed. Cookoff response can be moderated using high levels of the insensitive explosive, TATB, in combination with certain polymeric binders. The most suitable insensitive booster composition identified in this study can be produced in existing Australian defence production plant without the use of flammable and/or toxic organic solvents.

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Introduction

PBX main-charge fillings are less vulnerable to unplanned hazardous stimuli, such as bullet/fragment impact, cookoff, and sympathetic detonation, than are current TNT-based melt-cast compositions; they will allow munitions to meet IM criteria. To fully realize the benefit of this reduced vulnerability, it is essential that the fuze booster compositions used in conjunction with PBX fillings have similar low vulnerability, or insensitivity.

The main requirements for an insensitive booster composition are:

- it must be no more impact sensitive than tetryl (ie. Fof I > 90), in order to comply with fuze train safety guidelines;
- it should be less shock sensitive that tetryl, but must have sufficient shock sensitivity to initiate from fuzing systems; we chose the shock sensitivity of PBXW-7 Type II, an insensitive booster composition developed in the US, as being the minimum acceptable;
- it should have pickup behaviour and output power similar to those of tetryl;
- it should respond mildly (deflagration or less) under both fast and slow cookoff conditions, since violent (non-detonative) response of the booster may be sufficient to initiate the main charge; and
- it should be processible on a small batch scale in existing or easily acquired plant.

Insensitive PBX booster compositions being developed in the US and UK typically contain a thermally stable insensitive explosive (generally TATB) in conjunction with a nitramine (RDX or HMX) to confer the required shock sensitivity and performance, and a fluorocarbon binder (teflon or viton). However, these binders have poor adhesion to nitramines, and the coating efficiency is usually poor; compositions using these binders can be quite sensitive to impact and may exhibit poor cookoff behaviour.

We therefore undertook a program to develop an insensitive booster composition (as a moulding powder for production of pressed pellets) based on an alternative polymeric binder. This paper summarises the results of the program to date. A detailed description of the work is available in a series of MRL Technical Reports [1-5]. Selected results of impact sensitiveness, shock sensitivity and cookoff tests are presented in Tables 1-3, and these should be referred to in conjunction with the following sections. Experimental details are outlined in Annex A.

Binder Evaluations

1. Slurry-Coated RDX/EVA Compositions

Initially we chose to examine ethylene-vinyl acetate (EVA) copolymers as the desensitising binder, with RDX (Grade A, Class 1) as the energetic material. EVA copolymers had been reported to give good coatings on RDX crystals, giving compositions which exhibit mild cookoff response [6]. EVA copolymers are available with a wide range of vinyl acetate (VA) content, and this affects their physical properties. We chose to examine EVAs with VA contents ranging from 12 to 51%, as these polymers have glass transition temperatures and

softening points which will ensure that the binder neither melts nor becomes brittle during exposure to temperatures likely to be experienced in service.

The EVAs are commercially available as solid resins, and the moulding powders were prepared by a solvent-slurry coating process (see Annex A). We found that the coating efficiencies of the EVA copolymers, assessed using scanning electron microscopy, generally increase as the VA content increases, and decrease as the molecular weight increases. The coating efficiencies were found to influence impact sensitiveness, shock sensitivity and cookoff response.

Only one of the EVA copolymers, Elvax 210, was found to produce a composition which was sufficiently desensitized to impact (F of I = 130) to qualify for use as a booster explosive; the other EVAs gave little or no desensitization of the RDX to impact. Another batch of this composition, prepared later in the program, was found to have a lower but still acceptable F of I; the difference is believed to be due to variation in coating efficiency. We also prepared an RDX/Viton A composition by the slurry coating method; this was found to have an F of I of 65, indicating that fluorocarbon polymers can actually sensitize RDX-based compositions.

All the RDX/EVA compositions were found to have shock sensitivities intermediate between that of tetryl, the current booster material, and PBXW-7 type II. The binders with higher VA contents are more polar and gave more efficient coatings, leading to a reduction in shock sensitivity.

Only two of the solvent-slurry coated EVAs (Elvax 210 and Levapren 500) produced compositions with mild cookoff behavior at a fast heating rate; however, both these compositions gave violent responses at a slow heating rate. No correlation was observed between either the VA content of the EVA or the coating efficiency and cookoff response. The high explosiveness of RDX generally leads to violent cookoff response in compositions containing relatively low levels (up to 5%) of binder or desensitizer [6, 7], and the results for a large number of RDX/EVA compositions confirmed this.

From this work, we concluded that it is unlikely that an insensitive booster composition containing only RDX with an EVA coating would be attainable. However, some EVA copolymers showed promise in desensitizing RDX to impact and cookoff, and were later examined as binders in RDX-based compositions incorporating a second explosive (e.g. TATB or PETN).

2. Dispersion-Coated RDX/EVA And RDX/Acrylic Compositions

There are several disadvantages associated with the solvent-slurry process; it requires specialised processing equipment not currently used in Australian defence production facilities, and introduces additional hazards associated with the use of flammable, and often toxic, solvents. These problems can be avoided and existing equipment can be utilized if the compositions are prepared using aqueous polymer dispersions. These are coagulated, by

electrolyte addition or the use of thermal coagulation aids, in an aqueous RDX slurry to produce the moulding powders. We examined several commercially available EVA and polyacrylate dispersions; the latter class of polymers was chosen since polyacrylate binders are used in some insensitive main-charge PBX formulations.

The dispersion coating process generally gave poor coatings, with the precipitated polymer particles typically being deposited across the crystal surfaces but failing to coalesce to form a uniform coating. Three dispersions - Vinnapas EV2, Rhoplex HA-24 and Mowilith DM120 - gave soft precipitates that underwent partial coalescence to give greater coating efficiency; an additional coating of zinc stearate was applied to these compositions to give adequate flow properties, since the crystals with soft coatings tended to clump during drying. Various plasticizers and coalescing aids were used to modify unsatisfactory dispersions by softening the precipitated dispersions, inducing their coalescence and promoting polymer film formation; several coating/plasticizer combinations were found to give marked improvements in coating efficiency.

Of the dispersion coated compositions with no additives, only those which had effective coatings were significantly less impact sensitive than uncoated RDX. Several acrylic/plasticizer combinations gave compositions with good coatings and reduced impact sensitiveness. Our experiments showed that for each dispersion it was necessary to empirically determine the best plasticizer.

The dispersion coated compositions examined in detail all displayed adequate shock sensitivity, being less sensitive than tetryl and more sensitive than PBXW-7 Type II. The compositions containing the plasticized acrylic polymers had comparatively high shock sensitivity values, while those containing the softer polymers had somewhat lower values. We also noted that the unplasticized compositions gave higher quality pressed pellets than did the compositions containing plasticizers.

The two EVA dispersion coated samples gave widely varying cookoff responses at the fast heating rate, ranging from burning through to detonation, and violent responses at the slow heating rate. Two of the acrylic coated samples gave reduced responses (deflagration or mild explosion) at the fast heating rate, and one of these (containing Rhoplex HA-24) gave some moderation in cookoff response at the slow heating rate, although not sufficient to be an acceptable insensitive booster composition.

The conclusions from this work were that the use of plasticizers to enhance the coating efficiency of polymers which produce some desensitization, and the incorporation of other explosives to modify the cookoff response, should be further examined as methods of producing an acceptable insensitive booster explosive.

3. Plasticized EVA Binders

The effect of plasticizers on slurry coated EVA binders was assessed, with most work being conducted using an EVA binder, Levapren 408, which by itself had little effect on the impact

sensitiveness or cookoff behaviour of RDX. The effect of some plasticizers on RDX/Elvax 210, the best composition from the first phase of the program, was also assessed.

Incorporation of a range of plasticizers into RDX/Levapren 408 generally led to a decrease in impact sensitiveness and a slight increase in shock sensitivity. With RDX/Elvax 210 (with a low vinyl acetate content EVA), the incorporation of plasticizers generally led to increased impact sensitiveness. RDX/Levapren 408/Reofos 65 (a flame retardant plasticizer) showed a substantial reduction in the violence of the cookoff response; however, this same plasticizer produced more violent responses with RDX/Elvax 210. Other plasticizers also increased the cookoff violence of RDX/Elvax 210 at a fast heating rate, although some moderation was obtained at a slower rate.

Pressed pellets of the plasticized compositions were found to vary in their mechanical integrity after storage under ambient conditions, and evidence of plasticizer migration from the pressed pellets was observed for all compositions. These effects are believed to be due to some physical incompatibility of the EVAs with the plasticizers used.

Overall, it appeared that the most compatible EVA/plasticizer combinations can give appreciable reductions in cookoff response and impact sensitiveness of RDX-based booster compositions, but less compatible EVA/plasticizer combinations can have the opposite effect. Long-term stability of the compositions under service conditions could be a major problem. Accordingly, development of plasticized booster compositions was not pursued further. However, a compatible EVA/plasticizer combination may be a possible future option for a PBX binder if necessary.

Explosive Component Evaluations

1. RDX/PETN/Elvax 210 AND RDX/TATB/Elvax 210 Compositions

Partial replacement of the RDX with either a more thermally stable explosive (to reduce response by acting as an "explosive diluent" -see below) or a less thermally stable explosive (to initiate an earlier, milder response) were two options considered for modifying the cookoff response of RDX-based compositions. We examined these approaches using the RDX/Elvax 210 (95:5) composition as the base material, and incorporating either TATB or PETN, at levels ranging from 5% to 35%.

The RDX/PETN/Elvax 210 compositions were generally more impact sensitive than RDX, and these compositions would not comply with fuze system safety guidelines if used in fuze train systems below the shutter. All the compositions containing TATB had acceptable impact sensitiveness; those with higher levels of TATB gave comparatively low evolved gas volumes, indicating a reduction in the degree of reaction propagation ("explosiveness") after ignition. Replacement of the Grade A Class 1 RDX with a finer particle size (BUK Class 5) material increased the impact sensitiveness of the RDX/TATB/Elvax 210 (75:20:5) composition; however, the more sensitive material was still acceptable.

The shock sensitivities of all the RDX/PETN/Elvax 210 compositions were intermediate between those of tetryl and PBXW-7 Type II. In contrast, the RDX/TATB/Elvax 210 compositions, with the exception of RDX/TATB/Elvax 210 (85:10:5), were found to be extremely insensitive and would probably be unacceptable in practical fuze systems. Replacement of the Class 1 RDX with the finer particle size material increased the shock sensitivity of the RDX/TATB/Elvax 210 (75:20:5) composition to an acceptable level. This approach - tailoring shock sensitivity by controlling particle size - could be applied to other compositions which may be otherwise acceptable but have insufficient shock sensitivity.

The addition of PETN was expected to lead to earlier cookoff reactions at lower temperatures and to produce milder responses due to the initial reaction of the PETN producing an early release of confinement. At the slow heating rate such behaviour was observed, with the explosive surface temperature at reaction decreasing as the PETN content increased; milder responses were also obtained in most cases. However, at the fast heating rate there was no appreciable effect on the reaction temperature until a considerable amount of PETN (25-35%) had been added, and all the compositions gave more violent responses than the RDX/Elvax 210 (95:5) - explosions and/or detonations were obtained for all PETN levels. The results for the RDX/PETN/Elvax 210 compositions are presented graphically in Figure 1.

TATB is an insensitive heat-resistant explosive, and was expected to reduce the violence of the cookoff reaction by acting as an "explosive diluent". Although it will contribute to the reaction driving a detonation when initiated by a shock mechanism, when thermal decomposition occurs (as in initiation of reaction in a cookoff situation) it may act essentially as a diluent for the less thermally stable material (RDX). The results for the RDX/TATB/Elvax 210 compositions are presented graphically in Figure 2, and show that the reactions generally occur in the same temperature range as for RDX/Elvax 210 (95:5) and other RDX/EVA compositions [1], indicating that the reaction is being triggered by RDX in all these compositions. Similar behaviour has been reported for a series of RDX/TATB/PTFE compositions subjected to small-scale fuel fire cookoff tests [8]; the cookoff temperature did not increase until 60-75% TATB was incorporated into the composition. The TATB-containing compositions generally gave relatively mild responses at both heating rates. The RDX/TATB/Elvax 210 (65:30:5) composition gave similar cookoff responses to PBXW-7 Type II, and could be an acceptable insensitive booster composition if formulated with fine RDX to give acceptable shock sensitivity. However, we considered that further reduction of cookoff violence was desirable.

2. Other RDX/TATB-based Compositions

In an effort to further moderate the cookoff response of the RDX/TATB-based compositions, a series of compositions containing TATB (at levels up to 60%) and fine RDX (BUK, Class 5), to give adequate shock sensitivity, were prepared. Most compositions were prepared with the Elvax 210 EVA binder; several were also prepared using the best dispersion-coating material, the acrylate polymer Rhoplex HA-24.

The RDX(Class 5)/TATB/Elvax 210 compositions were generally found to be no more impact sensitive than tetryl, and, as expected, the fine RDX increased the shock sensitivity of these compositions to an acceptable level (greater than that of PBXW-7 Type II).

The range of responses for the various RDX(Class 5)/TATB/Elvax 210 compositions are displayed graphically for the fast and slow cookoff conditions in Figures 3 and 4 respectively. Increasing the TATB content from 0 to 60% causes a gradation in the fast cookoff response from detonations to burns; however, the limited results from slow cookoff experiments suggest that detonations can occur at all levels of TATB over this range.

The mildest overall cookoff response for a composition containing RDX(Class 5), TATB and 5% binder was observed for the RDX/TATB/Rhoplex HA-24/zinc stearate (50:45:4:1) composition. The mild fast cookoff response (deflagrations) can be attributed to the high level of TATB (45%) in this composition. The moderate slow cookoff behaviour (deflagration and mild explosion) is probably caused by the binder; the RDX(Grade A)/Rhoplex HA-24/zinc stearate (95:4:1) composition examined earlier (see above) gave only explosions (mild and violent) in slow cookoff tests compared to detonations which are usually observed for compositions with this high nitramine content. To further moderate the overall cookoff response the binder level was raised to 6-7%, with the proportion of zinc stearate being increased to improve the flow and handling properties of the moulding powders; none of these compositions gave responses more violent than deflagrations. The RDX/TATB/Rhoplex HA-24/zinc stearate (49.5:44.5:3:3) composition has the best flow and handling properties, and is the preferred insensitive booster composition in this series. It has the additional advantage that it is prepared using the aqueous dispersion coating process, rather than the solvent-slurry process.

3. HMX-based Compositions

The effect of replacing RDX with HMX was assessed for several compositions. Both coarse and fine HMX (corresponding to the Grade A Class 1 RDX and the Class 5 BUK RDX, respectively) were used, and HMX/binder and HMX/TATB/binder compositions were prepared using the slurry-coated EVA binders, Elvax 210 and Levapren 500, and the dispersion-coated acrylate binder, Rhoplex HA-24.

HMX is more impact sensitive than RDX (F of I values of 50-55, compared to 80 for RDX); all the HMX-based compositions, even one containing 20% TATB, had F of I values less than that of tetryl. None of these compositions would meet the current fuze safety guidelines for impact sensitiveness.

Shock sensitivity was only determined for a single HMX-based composition (HMX(fine)/TATB/Elvax 210), and was identical to that for the equivalent RDX-based composition.

Replacement of RDX with HMX in RDX/EVA 95:5 compositions had little significant effect on the cookoff response at the fast heating rate; at the slow heating rate, more moderate

responses were obtained. Compositions containing fine HMX and higher binder levels (7.5% Levapren 500, or 8% HA-24/ZnSt) gave very mild responses at both fast and slow heating rates. The cookoff response of the HMX/TATB/Elvax 210 composition was similar to that of the equivalent RDX-based composition.

Although HMX-based compositions were found to give very mild cookoff responses, their impact sensitiveness is such that they are unsuitable for use as booster compositions under current fuze safety guidelines. However, such compositions may be worthy of further study for applications where improved cookoff response and/or increased power are required, and impact sensitiveness requirements are less stringent.

Explosive Performance

In the various phases of the development program, the compositions were assessed on the basis of impact sensitiveness, shock sensitivity and cookoff response, against the criteria described in the introduction. Rather than experimentally determining the explosive performance of the many compositions examined, we used the Kamlet-Jacobs empirical predictive method [9] to confirm that the compositions would have performance (velocity of detonation (VoD) and detonation pressure) equivalent to, or better than, that of tetryl. Results of these calculations, for materials at 90% TMD, are presented in Table 4, and indicate that all compositions should give acceptable performance. The VoD, detonation pressure and critical diameter of the preferred composition, RDX/TATB/Rhoplex HA-24/ZnSt 49.5:44.5:3:3, is being determined experimentally.

Current Status

The preferred compositions, RDX/TATB/Rhoplex HA-24/ZnSt 49.5:44.5:3:3, is being trialled in full-scale IM tests in the explosive train (AN2 fuze booster and exploder pellets) of PBX-filled 5"/54 shells. Mild responses of shells containing this composition have been obtained in fast cookoff and bullet impact tests, and for some acceptor rounds in sympathetic detonation tests. Some acceptors in the sympathetic detonation tests gave high order responses; however, this is believed to be due to direct initiation of the PBX main charge, rather than initiation of the booster/exploder pellets.

During preparation of the pellets for the full-scale IM tests, we found that the material produced in laboratory-scale batches did not flow sufficiently well to be used in automatic pelleting operations. Minor modification of the binder system/coating operation, to produce a satisfactory granulation of the moulding powder, is also being undertaken. When complete, we will have produced an Australian insensitive booster composition which fully meets all requirements.

References

1. Dagley, I.J., Spencer, H.J., Louey, C.N. and Parker, R.P. (1989). An Evaluation of Ethylene-Vinyl Acetate Copolymers as Desensitizers for RDX in Insensitive Booster Compositions Prepared by the Slurry Coating Technique. MRL Technical Report MRL-TR-89-33.

2. Dagley, I.J., Montelli,L., Parker, R.P. and Louey, C.N. (1989). *Preparation, Characterization and Cookoff Behaviour of Booster Compositions Prepared from RDX and Acrylic or Ethylene-Vinyl Acetate Dispersions*. MRL Technical Report MRL-TR-89-44.

3. Dagley, I.J., Parker, R.P., Montelli,L. and Louey, C.N. (1991). *Plasticized Ethylene-Vinyl Acetate Binders for Insensitive Booster Compositions.* MRL Technical Report MRL-TR-91-34.

4. Dagley, I.J., Parker, R.P., Montelli, L. and Louey, C.N. (1993). *Mixed High Explosives for Insensitive Booster Compositions.* MRL Technical Report MRL-TR-92-22.

5. Dagley, I.J., Montelli, L. and Parker, R.P. (1993). *Pressed Booster Compositions with Moderate Cookoff Responses.* MRL Technical Report MRL-TR-93-41.

6. Anderson, C.M. and Pakulak, J.M. (1977/78). *Journal of Hazardous Materials*, **2**, 143.

7. Parker, R.P. (1989). *Establishment of a Super Small-scale Cookoff Bomb (SSCB) Test Facility at MRL*. MRL Technical Report MRL-TR-89-9.

8. Kabik, I and Ringbloom, V.D. (1983). *Cookoff Resistant Booster Explosive*, US Patent 4,394,197.

9. Kamlet, M.J. and Jacobs, S.J. (1968). *Journal of Chemical Physics*, **48**, 23.

10. UK Sensitiveness Collaboration Committee (1980). *Explosives Hazard Assessment, Manual of Tests, SCC No. 3*, Test No. 1/72.

11. Wolfson, M.G. (1983). *The MRL Small Scale Gap Test for Assessment of Shock Sensitivity of High Explosives*. MRL Report MRL-R-896.

12. Pakulak, J.M. Jr. and Cragin, S. (1983). *Calibration of a Super Small-scale Cookoff Bomb (SSCB) for Predicting Severity of the Cookoff Reaction.* (NWC TP 6414). China Lake, CA, USA: Naval Weapons Center.

Table 1: Impact Sensitiveness of Selected Compositions and Reference Explosives [a]

Composition	F of I	Gas Evolution (mL)
Slurry -Coated RDX/EVA Compositions		
RDX/Elvax 650 (12% vinyl acetate) 95:5	75	14
RDX/Elvax 210 (28% vinyl acetate) 95:5	130, 90	15, 16
RDX/Levapren 400 (40% vinyl acetate) 95:5	80	16
RDX/Levapren 408 (40% vinyl acetate) 95:5	75	15
RDX/Levapren 500 (50% vinyl acetate) 95:5	85	9
Dispersion-Coated RDX/EVA Compositions		
RDX/Mowilith DM105 95:5	75	14
RDX/Mowilith DM120/ZnSt 95:4:1	105	11
RDX/Vinnapas EV2/ZnSt 95:3.5:1.5	125	13
Dispersion-Coated RDX/Acrylic Compositions		
RDX/Acronal 230D 95:5	70	15
RDX/Acronal 230D/Reofos 65 [b]/ZnSt 95:4:0.4:1	90	12
RDX/Acronal 250D 95:5	80	17
RDX/Acronal 250D/DOP [c] 95:4:0.4:1	85	15
RDX/Rhoplex HA-24/ZnSt 95:4:1	110	11
Plasticized Slurry-Coated RDX/EVA Compositions		
RDX/Levapren 408/Reofos 65 95:5:0.5	90	10
RDX/Levapren 408/DOP 95:5:0.5	100	10
RDX/Levapren 408/Edenol DCHP [d] 95:5:0.5	105	11
RDX/Elvax 210/Reofos 65 95:5:0.5	100	17
RDX/Elvax 210/Edenol DCHP 95:5:0.5	85	13
RDX/PETN/Elvax 210 Compositions		
90:5:5	75	15
80:15:5	65	10
60:35:5	50	11
RDX/TATB/Elvax 210 Compositions		
85:10:5	90	14
80:15:5	125	14
75:20:5	115	7
75:20:5 - Class 5 RDX	90	4
65:30:5	115	3
65:30:5 - Class 5 RDX	85, 95	2, 10
50:45:5 - Class 5 RDX	90, 100	2, 4
RDX(Class 5)/TATB/Rhoplex HA-24/Zinc Stearate		
50:45:4:1	95	7
49.5:44.5:3:3	95,115,120	2,7,5
HMX-based Compositions		
HMX(coarse)/Elvax 210 95:5	80	9
HMX(coarse)/Levapren 500 95:5	65	8
HMX (fine)/Rhoplex HA-24/ZnSt 94:3:3	50	1
HMX (fine)/Rhoplex HA-24/ZnSt 92:5.3:2.7	70	7
HMX(fine)/TATB/Elvax 210 75:20:5	85	5

Table 1: Continued

Composition	**F of I**	**Gas Evolution (mL)**
Reference Explosives		
RDX	80	na
Tetryl, granular	90, 110	na, 16
Tetryl crystalline	105	16
PBXW-7 Type II [e]	90	4
RDX/Viton A 95:5 - prepared by slurry coating method	65	14
TATB	>200	0.5
PETN	30, 50	na, na
HMX	50	12

a. Selected data from references [1-5]; original references for Reference Explosives are also given therein.
b. Reofos 65 - triarylphosphate ester flame retardant plasticizer.
c. DOP - dioctylphthalate plasticizer.
d. Edenol DCHP - dicyclohexylphthalate plasticizer
e. RDX/TATB/Viton A 35:60:5

Table 2: Shock Sensitivity of Selected Compositions and Reference Explosives [a].

Composition	Shock Sensitivity (mm) [b] $M_{50\%}$	Range	Std. Dev.
Slurry-Coated RDX/EVA Compositions			
RDX/Elvax 210 (28% vinyl acetate) 95:5	2.23	2.34 - 2.11	0.054
RDX/Levapren 400 (40% vinyl acetate) 95:5	2.11	2.14 - 2.07	0.016
RDX/Levapren 408 (40% vinyl acetate) 95:5	1.85	1.98 - 1.81	0.018
RDX/Levapren 500 (50% vinyl acetate) 95:5	1.79	1.85 - 1.72	0.031
Dispersion-Coated RDX/EVA Compositions			
RDX/Mowilith DM120/ZnSt 95:4:1	2.18	2.25 - 2.11	0.032
RDX/Vinnapas EV2/ZnSt 95:3.5:1.5	2.17	2.24 - 2.11	0.028
Dispersion-Coated RDX/Acrylic Compositions			
RDX/Acronal 230D/Reofos 65/ZnSt 95:4:0.4:1	2.63	2.71 - 2.54	0.039
RDX/Acronal 250D/DOP 95:5:0.5	2.65	2.77 - 2.54	0.052
RDX/Rhoplex HA-24/ZnSt 95:4:1	2.17	2.22 - 2.13	0.021
Plasticized Slurry-Coated RDX/EVA Compositions			
RDX/Levapren 408/Reofos 65 95:5:0.5	2.02	2.07 - 1.97	0.023
RDX/Levapren 408/DOP 95:5:0.5	2.18	2.19 - 2.12	0.018
RDX/Levapren 408/Edenol DCHP 95:5:0.5	1.98	2.07 - 1.89	0.041
RDX/PETN/Elvax 210 Compositions			
90:5:5	2.35	2.38 - 2.33	0.012
80:15:5	2.45	2.49 - 2.40	0.022
70:25:5	2.84	2.89 - 2.79	0.024
60:35:5	2.99	3.07 - 2.90	0.039
RDX/TATB/Elvax 210 Compositions			
85:10:5	1.60	1.67 - 1.54	0.030
75:20:5	.69	0.71 - 0.68	0.008
75:20:5 - Class 5 RDX	2.53	2.59 - 2.47	0.028
65:30:5	0.30	0.31 - 0.28	0.007
65:30:5 - Class 5 RDX	2.54	2.60 - 2.48	0.029
50:45:5	1.96	1.98 - 1.93	0.012
RDX(Class 5)/TATB/Rhoplex HA-24/ZnSt			
49.5:44.5:3:3	1.85	1.87 - 1.82	0.012
HMX/TATB/Elvax 210			
75:20:5 - fine HMX	2.53	2.60 - 2.46	0.033
Reference Explosives			
Tetryl, granular	3.259	3.315 -3.203	0.026
Tetryl, crystalline	2.814	2.858 -2.772	0.021
PBXW-7 Type II	1.415	1.448 -1.382	0.015
RDX, Grade A Class 1	3.360	3.622 -3.100	0.120
	Decibangs [c]		
RDX	3.76		
PETN	2.468		
TATB	9.63		

a. Selected data from references [1-5]; original references for Reference Explosives are also given therein.
b. All results for compositions pressed to 90% TMD.
c. Related to the attenuator thickness (t, in mils) for a 50% probability of detonation by the equation:
$$Dbg = 30 - 10 \log t$$

Table 3: Cookoff Test (SSCB) Results for Selected Compositions and Reference Explosives. [a]

Composition	Response (Surface Temperature, ºC; Time, s) [b] Fast Heating Rate [c]	Slow Heating Rate
Slurry-Coated RDX/EVA Compositions		
RDX/Elvax 650 (12% vinyl acetate) 95:5	Detonation (252; 256)	
	Explosion, violent (240; 259)	
RDX/Elvax 210 (28% vinyl acetate) 95:5	Burn (245; 235)	Detonation (217; 1628)
	Deflagration (234; 238)	Detonation (220; 1681)
	Explosion, mild (237; 246)	
RDX/Levapren 408 (40% vinyl acetate) 95:5		Detonation (266; 284)
	Detonation (230; 250)	
RDX/Levapren 500 (50% vinyl acetate) 95:5		Deflagration (263; 258)
	263)Explosion, mild (217; 1592)	
	Deflagration (249; 263)	Detonation (217; 1659)
Dispersion-Coated RDX/EVA Compositions		
RDX/Mowilith DM120/ZnSt 95:4:1	Burn (224; 235)	Detonation (222; 1484)
	Deflagration (242; 263)	
	Detonation (242; 252)	
RDX/Vinnapas EV2/ZnSt 95:3.5:1.5	Burn (241; 267)	Detonation (217; 1662)
	Deflagration (237; 276)	
	Detonation (242; 252)	
Dispersion-Coated RDX/Acrylic Compositions		
RDX/Acronal 250D/DOP [d]/ZnSt 95:5:0.5	Explosion, mild (242; 266)	Detonation (220; 1642)
	Explosion, mild (238;238)	
RDX/Rhoplex HA-24/ZnSt 95:4:1	Deflagration (228; 239)	Explosion, mild (223; 1573)
	Explosion, mild (234; 255)	Explosion, violent (223; 1570)
Plasticized Slurry-Coated RDX/EVA Compositions		
RDX/Levapren 408/Reofos 65 95:5:0.5	Burn (251; 350)	Explosion (218; 1692)
	Explosion, mild (228; 275)	Explosion (211; 1838)
RDX/Levapren 408/Edenol	Explosion (249; 365)	Detonation (218; 1473)
DCHP 95:5:0.5	Detonation (231; 260)	Detonation (223; 1808)
RDX/Elvax 210/Reofos 65 95:5:0.5	Detonation (235; 282)	Explosion (211; 1976)
		Detonation (213; 1688)
RDX/Elvax 210/Edenol DCHP 95:5:0.5	Explosion, mild (237; 371)	Explosion (206; 1779)
	Detonation (227; 260)	Detonation (223; 1588)
RDX/TATB/Elvax 210 Compositions		
see Figure 1		
RDX/PETN/Elvax 210 Compositions		
see Figure 2		
RDX(Class 5)/TATB/Elvax 210 Compositions		
see Figures 3 and 4		

Table 3: Continued.

Composition	Response (Surface Temperature, °C; Time, s) [b] Fast Heating Rate [c]	Slow Heating Rate
RDX(Class 5)/TATB/Rhoplex HA-24/Zinc Stearate		
50:45:4:1	Deflagration (234; 267)	Deflagration (210; 1507)
	Deflagration (251; 315)	Deflagration/Explosion (211; 1621)
49.5:44.5:3:3	Burn (245; 306)	Deflagration, mild (212;1735)
	Burn (237; 272)	Deflagration (212; 1419)
	Burn (230; 297)	Deflagration, mild (212;1524)
	Deflagration (249; 321)	Deflagration (211; 1516)
HMX-based Compositions		
HMX/Levapren 500 95:5	Burn (278; 293)	Deflagration (257; 2459)
	Deflagration/explosion (280;316)	Explosion, mild (255; 2588)
HMX/Levapren 500 92.5:7.5	Burn (278; 321)	Burn (256; 2312)
- fine HMX	Deflagration (284; 371)	Deflagration (254; 2538)
HMX/Rhoplex HA-24/ZnSt	Burn, mild (270; 399)	Burn, mild (245; 2778)
92:5.3:2.7 - Class 5 HMX		Burn (246; 2488)
HMX/TATB/Elvax 210	Burn (278; 384)	Burn (254; 1887)
75:20:5 - fine HMX	Deflagration (286;317)	Explosion, mild (246; 2076)
Reference Compositions		
Tetryl	Detonation (257; 239)	See note d.
	Detonation (268; 240)	
PBXW-7, Type II	Burn (240; 252)	Explosion (213; 1657)
	Burn (241; 337)	Detonation (215; 1516)
	Burn (265;266)	Deflagration (221; 1679)
RDX/Viton A 95:5	Detonation (260; 271)	Detonation (217; 1577)

a. Selected data from references [1-5]; original references for Reference Explosives are also given therein.
b. All results for compositions pressed to 90% TMD.
c. Generally, compositions which gave violent responses at the fast heating rate were not tested at the slow heating rate.
d. The response of tetryl at the slow heating rate cannot be assessed in the SSCB due to loss of molten sample prior to reaction [7]. A detonation response is assumed.

Figure 1: Cookoff Test Results for RDX/PETN/Elvax 210 Compositions.

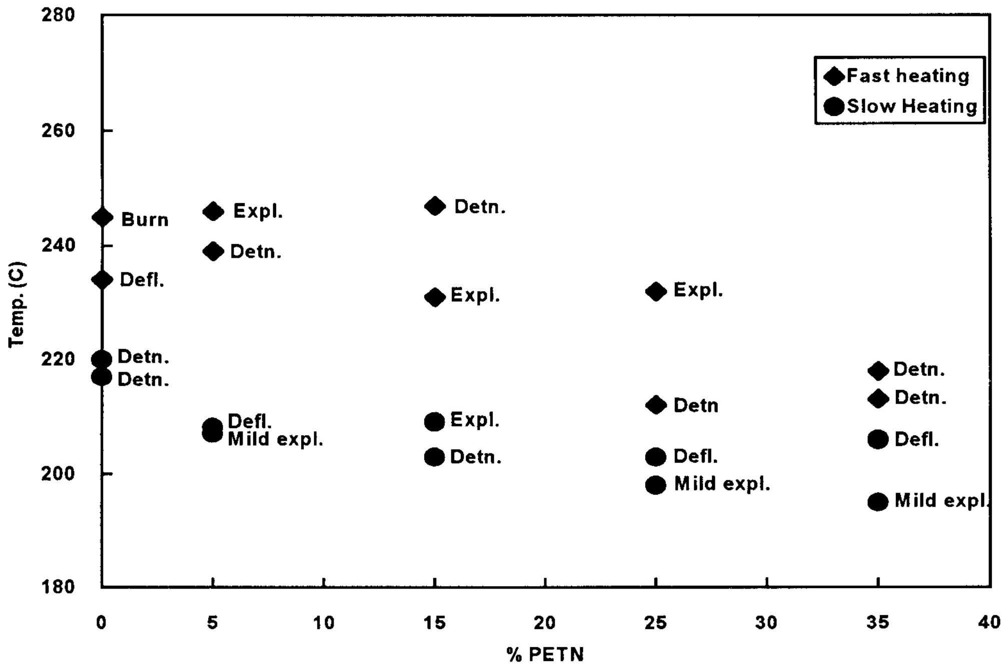

Figure 1: Cookoff Test Results for RDX/PETN/Elvax 210 Compositions.

Figure 2: Cookoff Test Results for RDX/TATB/Elvax 210 Compositions.

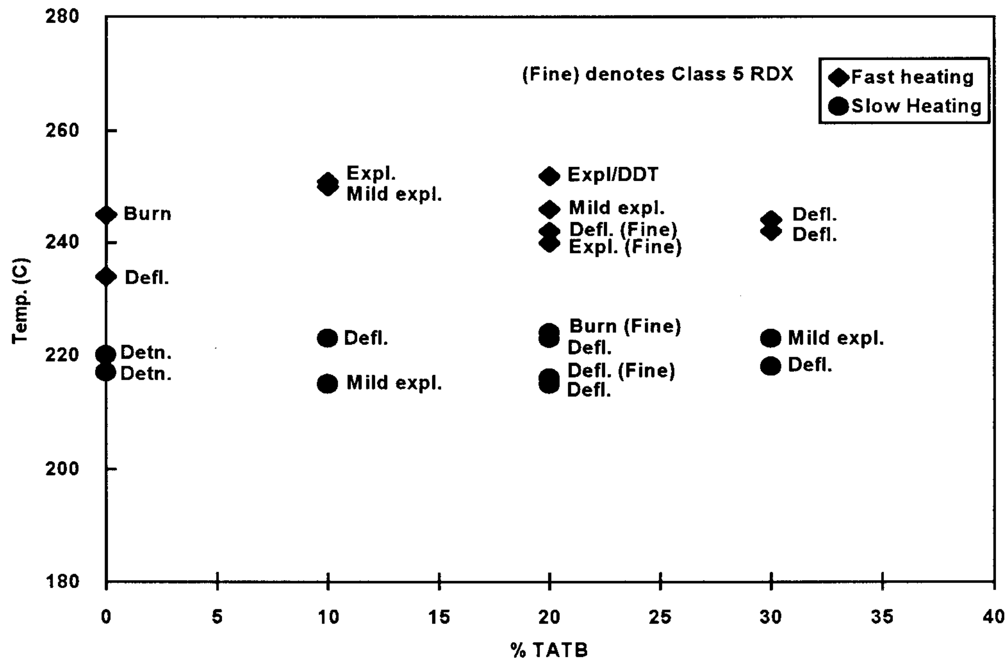

Figure 2: Cookoff Test Results for RDX/TATB/Elvax 210 Compositions.

Figure 3: Range of fast cookoff (SSCB) test responses for RDX/TATB/Elvax 210 (5%) compositions plotted against TATB content.

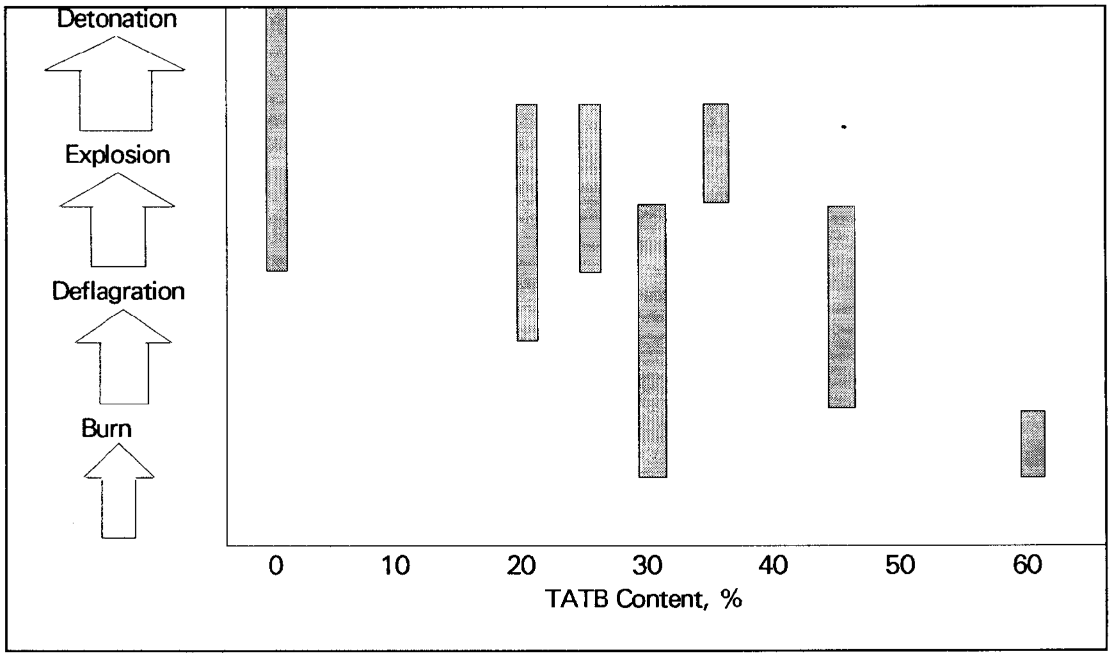

Figure 3: *Range of fast cookoff (SSCB) test responses for RDX/TATB/Elvax 210 (5%) compositions plotted against TATB content.*

Figure 4: Range of slow cookoff (SSCB) test responses for RDX/TATB/Elvax 210 (5%) compositions plotted against TATB content .

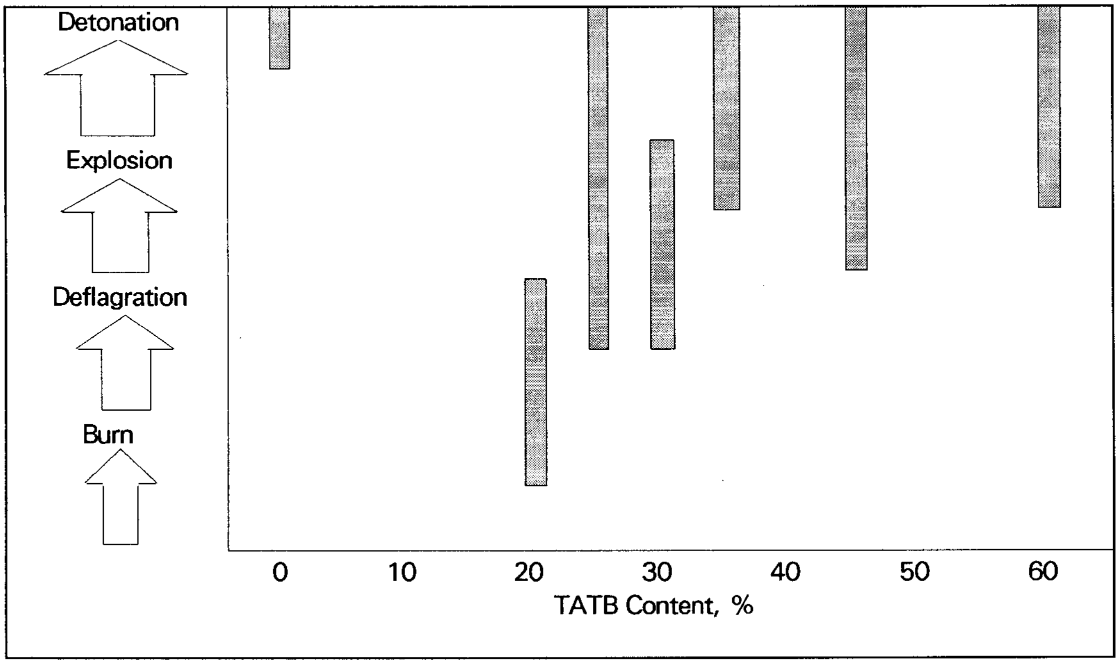

***Figure 4:** Range of slow cookoff (SSCB) test responses for RDX/TATB/Elvax 210 (5%) compositions plotted against TATB content.*

Table 4: Predicted Explosive Performance of Compositions [a].

Composition	VoD (mm/µs)	Pcj (kbar)
Tetryl	7.237	212
PBXW-7 Type II	7.592	247
RDX	8.187	279
HMX	8.484	310
TATB	7.357	236
PETN	8.112	271
RDX/binder 95:5	7.738	242
RDX/TATB/binder 75:20:5	7.583	234
RDX/TATB/binder 50:45:5	7.376	224
RDX/PETN/binder 75:20:5	7.728	241
HMX/binder 95:5	7.987	266

a. Calculations using Kamlet-Jacobs method, for compositions at 90% TMD.

b. Both EVA and HA-24 binders were approximated by polyethylene for the calculations, since heat of formation data was not available for these materials. The effect of this change is expected to be small.

Annex A - Experimental Methods

Preparative Methods

Slurry Coating Process

A slurry of RDX in water (1:3 mass ratio) was vigorously stirred, and a small amount of Mowiol 4-88 (0.001% of RDX content) was added. The Mowiol is a partially saponified polyvinyl alcohol which acts as a protective colloid to prevent flocculation, and also stabilizes the emulsion formed between the polymer solution and the water. The required amount of EVA copolymer, as a 10% solution in toluene, was slowly added and vigorous agitation continued for 15 minutes. When plasticizers were used, they were also dissolved in the toluene. The mixture was then heated to 60-65°C and maintained at that temperature until most of the solvent was removed and hard moulding granules had formed; it was then cooled to 30°C and the product filtered off, washed and dried.

Dispersion Coating Process

The dispersion coated compositions were prepared by stirring a slurry of RDX in water (1:1 mass ratio) at room temperature and then adding the appropriate amount of aqueous dispersion of the polymer. Thermal coagulation aids (if required) were then added and the temperature was raised (typically to 45-60°C for the acrylic dispersions, and 70°C for the EVA dispersions), and a solution of electrolyte [$CaCl_2$ or $Al_2(SO_4)_3$] was then added dropwise to effect coagulation of the polymer. The slurry was then maintained at a higher temperature (typically 80-100°C) until coagulation was complete and the aqueous phase was clear. The stirred slurry was then chilled in ice-water and the product filtered off, washed and dried.

When plasticizers or coalescing aids were used, these were thoroughly stirred with the polymer dispersion prior to preparation of the composition as described above. When zinc stearate (ZnSt) coatings were required to give suitable handling and flow characteristics to the moulding powder, these were applied as a final step in the preparation by adding sodium stearate solution followed by zinc sulphate solution; the product was then filtered off, washed and dried as before.

Characterisation Methods

Rotter Impact Sensitiveness: Figure of Insensitiveness (F of I)
The impact sensitiveness of the compositions was determined using a Rotter apparatus [10] fitted with a 5 kg drop-weight. The results were obtained using either 25 or 50 caps and tests were performed using a Bruceton up-down procedure. The F of I values quoted are derived from the drop height for a 50% probability of initiation; they are quoted relative to RDX Grade F = 80 and are rounded to the nearest 5 units. The average gas volumes for positive results are also quoted.

Shock Sensitivity: Small Scale Gap Test

Shock sensitivity data was obtained using the MRL small scale gap test (SSGT) [11]. The donor was a UK Mk 3 exploding bridgewire detonator and the shock was attenuated by brass shim. The acceptor was two 12.7 mm diameter x 12.7 mm cold-pressed cylinders of the explosive under study. A detonation was confirmed using a mild steel witness block. The results were obtained from 20 to 30 firings using a Bruceton up-down procedure; they are quoted in mm of brass shim for a 50% detonation probability, together with 95% confidence limits and standard deviation.

Cookoff Test

The cookoff behaviour of the compositions was assessed using the Super Small-scale Cookoff Bomb [7,12]. The SSCB samples consisted of four pellets 16 mm diameter x 16 mm long, pressed to 90% theoretical maximum density (TMD), with a total mass of approximately 20 g. Tests were performed at both fast (approximately 1°C/second) and slow (approximately 0.1°C/second) heating rates. In some cases a modified (shorter, symmetrical) SSCB test assembly [3] was used. The results presented include the type of response obtained, the explosive surface temperature at reaction and the time to reaction.

Viewgraph 1

An Australian Insensitive Booster Composition

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DSTO

Presented to 26th DoD ESB Explosives Safety Seminar
by GPCAPT W. Mayne, PAOC

Viewgraph 2

Insensitive Booster Composition Requirements

- **Impact sensitiveness less than tetryl**
- **Shock sensitivity between tetryl and PBXW-7 Type II**
- **Mild cookoff response**
- **Detonation performance similar to tetryl**
- **Easily processible**

Viewgraph 3
RDX/EVA Compositions

- **ethylene-vinyl acetate desensitizing binder**
  - **vinyl acetate content 12-51%**
  - **slurry coating process, 5% on RDX (Grade A, Class 1)**
- **generally poor desensitization to impact**
  - **RDX/Elvax 210 95:5 - F of I values 130, 90**
- **shock sensitivities between tetryl and PBXW-7**
- **Elvax 210 and Levapren 500 gave mild fast cookoff response; all gave violent slow cookoff response**
- **insensitive booster composition containing only RDX and EVA is not attainable**

Viewgraph 4

RDX/EVA and RDX/acrylic - Dispersion Coated Compositions

- aqueous EVA or polyacrylate polymer dispersions
  - coating effected by coagulation via electrolye addition
  - plasticizers used to improve coating efficiency
  - zinc stearate to improve handling / flow properties
- reduced impact sensitiveness with good coatings
- shock sensitivities between tetryl and PBXW-7
- varied cookoff responses
- acrylic Rhoplex HA-24 best candidate, but not acceptable
- plasticizers may enhance binder desensitization;
  other explosives needed to modify cookoff response

Viewgraph 5

Plasticized EVA Binders

- 10% plasticizer in slurry-coated EVAs
- effect on impact sensitiveness, shock sensitivity and cookoff response varied
- same plasticizer can have opposite effects with different EVAs
- pressed pellet integrity; plasticizer migration
- compatible EVA/plasticizer combinations can reduce impact sensitiveness and cookoff response
- long term stability questionable; further development not pursued

Viewgraph 6

RDX/PETN/Elvax 210 Compositions

- **based on RDX/Elvax 210 95 : 5, with 5 - 35 % PETN**
  - **use of less thermally stable explosive, to initiate an earlier, milder cookoff response**
- **milder response at lower temperatures at slow heating rate; violent responses at fast heating rate**
- **impact sensitiveness - F of I values < 80 - unacceptable**
- **shock sensitivities between tetryl and PBXW-7**

Viewgraph 7

RDX/TATB/Elvax 210 Compositions

- **based on RDX/Elvax 210 95 : 5, with 10 - 30 % TATB**

    - **use of more thermally stable explosive, to reduce cookoff response by acting as “explosive diluent”**

- **milder responses at both heating rates; reaction probably triggered by RDX**

- **impact sensitiveness less than tetryl**

- **extremely shock insensitive - unacceptable**

- **modify shock sensitivity by use of fine RDX; further moderate cookoff response**

Viewgraph 8

Other RDX/TATB Compositions

- RDX(Class 5)/TATB/Elvax 210 - up to 60% TATB
  - impact sensitiveness less than tetryl
  - shock sensitivities between tetryl and PBXW-7
  - gradation in fast cookoff response, to burn at 60% TATB; violent responses at slow heating rate
- RDX(Class 5)/TATB/HA-24/ZnSt
  - best cookoff response from 50:45:4:1 composition; mild fast cookoff response due to high TATB level, mild slow response due to binder system
  - increased binder level to 6 - 7 %; zinc stearate content increased to improve flow / handling properties

Viewgraph 9

Preferred Composition

- **RDX/TATB/Rhoplex HA-24/ZnSt 49.5 : 44.5 : 3 : 3**

  - **Impact sensitiveness: F of I 95, 115, 120**

  - **Shock sensitivity: M50% 1.85 mm**

  - **Cookoff response, fast: Burn / deflagration**
    " " slow: Mild deflagration / deflagration

- **prepared by aqueous dispersion coating process; modification to improve granulation**

Viewgraph 10

HMX-based Compositions

- **replacement of RDX with HMX**
  - **HMX/EVA; HMX/TATB/Elvax 210; HMX/HA-24/ZnSt**
- **all more impact sensitive than tetryl**
- **shock sensitivity as for RDX-based composition**
- **very mild cookoff responses with fine HMX and slightly higher binder levels**
- **may be useful where improved cookoff response and/or increased explosive performance required, with less stringent impact sensitiveness requirements**

Viewgraph 11

Explosive Performance

Kamlet-Jacobs calculations to confirm performance equivalent to or better than tetryl

Composition (at 90% TMD)	VoD (mm/µs) Pcj (kbar)
Tetryl	7.237 212
PBXW-7 Type II	7.592 247
RDX/binder 95:5	7.738 242
RDX/TATB/binder 75:20:5	7.583 234
RDX/PETN/binder 75:20:5	7.728 241
RDX/TATB/binder 50:45:5	7.376 224
HMX/binder 95:5	7.987 266

Viewgraph 12

Current Status

- **Performance of preferred composition being determined experimentally**

- **IM trials of preferred composition in explosive train of PBX-filled 5”/54 shells**

  - **FCO, SCO, BI, SD tests generally mild responses violent responses due to main filling, rather than booster**

- **Minor modification of binder system / coating operation to give granulation suitable for automatic pelleting equipment**